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EVALUATION OF BUTLER AM2 LANDING MAT

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W. B. Fenwick

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Sponsored by

Naval Air Engineering Center
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ASSOCIATED REPORTS

Report No.	Title	Date
MP 4-501	Development of CBR Design Curve for M9M2 Landing Mat	June 1962
MP 4-581	Evaluation of M9M1 Landing Mat	July 1963
MP 4-599	Development of CBR Design Curves for AM1 Landing Mat	Sept 1963
MP 4-615	Development of CBR Design Curves for Harvey Aluminum Landing Mat [AM2]	Jan 1964
MP 4-655	Development of CBR Design Curve for Modified AM1 Landing Mat	June 1964
MP 4-656	Evaluation of Convair Landing Mat	June 1964
MP 4-747	Evaluation of Harvey Modified AM2 Landing Mat	Oct 1965
MP 4-753	Evaluation of Washington Aluminum Company AM2 Landing Mat	Nov 1965
	Evaluation of Various Sizes of Butler AM1 Landing Mat	(In preparation)
	Evaluation of Various Sizes of Harvey Aluminum AM2 Landing Mat	(In preparation)
	Evaluation of AM2 Landing Mat Replacement Panels and Keylock Assemblies	(In preparation)

FOREWORD

This report is the ninth in a series published on landing mat tests performed by the U. S. Army Engineer Waterways Experiment Station (WES) for the Naval Air Engineering Center (NAEC), Philadelphia, Pa. (formerly the Naval Air Material Center, NAMC). The investigation reported herein was authorized by the NAMC in Project Order No. 3-4019, dated 29 October 1962, and was conducted by the WES during the period November 1963 through January 1964.

Engineers of the WES Soils Division who were actively engaged in the planning, testing, analysis, and report phases of the study were Messrs. W. J. Turnbull, W. G. Shockley, A. A. Maxwell, W. L. McInnis, C. D. Burns, W. B. Fenwick, and M. J. Mathews. This report was prepared by Messrs. Fenwick and Mathews.

Col. Alex G. Sutton, Jr., CE, and Col. John R. Oswalt, Jr., CE, were Directors of the WES during the conduct of this investigation and the preparation of this report. Mr. J. B. Tiffany was Technical Director.

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SUMMARY

This study was conducted to compare the performance of aluminum landing mat fabricated by Butler Manufacturing Co., Kansas City, Mo., with that designed and fabricated by Harvey Aluminum, Inc., Torrance, Calif. The Harvey aluminum mat was tested and the results were reported earlier by the U. S. Army Engineer Waterways Experiment Station (WES). The primary method of comparison was by using CBR design curves which were developed to represent 1600 operational cycles of an aircraft having a 60,000-lb gross weight with a single-wheel, main-gear assembly load of 27,000 lb and a 30-7.7 tire inflated to 400 psi. CBR design curves were also developed for 1600 passes of a 39,000-lb single-wheel load applied in a single track to represent the calculated loading imposed on the landing mat during launching of the 60,000-lb aircraft by catapult.

A test section consisting of three items with different subgrade materials at different strengths and surfaced with the Butler mat was constructed and subjected to accelerated traffic of single-wheel loads ranging from 27,000 to 33,000 lb with a 30-7.7 tire inflated to 400 psi.

It was concluded that:

a. Although the performance of the Butler AM2 mat was not as good as the original Harvey mat, the test data indicate that the Butler mat will sustain 1600 cycles (188 coverages) of aircraft operations of a 60,000-lb aircraft with a 27,000-lb single-wheel load and tire inflation pressure of 400 psi when placed on a subgrade having a CBR of 8.8 or greater throughout the period of traffic as compared to a required CBR of 6.3 for the Harvey aluminum mat. This conclusion includes catapult launchings in which the vertical load on a single wheel will not exceed 27,000 lb during the launching operations.

b. Based on the equivalent wheel load concept described in this report, and ignoring the deficiencies of the mat core, the Butler aluminum mat will sustain 1600 passes of a 39,000-lb single-wheel load with tire inflation pressure of 400 psi applied in a single path when placed on a subgrade having a CBR of 10.9 or greater throughout the period of traffic as compared to a required CBR of 7.4 for the Harvey aluminum mat. However, based on the mat core failures that occurred

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during the single-track traffic with 33,000-lb single-wheel load, it is concluded that the Butler mat core design is inadequate to sustain 1600 passes of a 39,000-lb single-wheel load with tire inflation pressure of 400 psi applied in a single path, regardless of subgrade strength.

EVALUATION OF BUTLER AM2 LANDING MAT

PART I: INTRODUCTION

Background

1. Since August 1961 the U. S. Army Engineer Waterways Experiment Station (WES) has been engaged in a comprehensive test program for the Naval Air Material Center (now Naval Air Engineering Center, NAEC) to evaluate various types of landing mats for use in surfacing small airfields for tactical support (SATS) in amphibious operations. A SATS has been defined as a small, quickly constructed, tactical support airfield of temporary nature, capable of sustaining operations of modern jet aircraft of the Marine Corps employing assisted takeoffs and arrested landings. The minimum operational installation must be ready for use in the objective area within the first three to five days of an amphibious assault. The runway must be capable of withstanding the heavy wheel loads of the using jet aircraft, arresting-hook impacts of aircraft making arrested landings, and heat blasts from tailpipes of jet engines during takeoffs, and it must remain serviceable with minimum maintenance for 1600 aircraft operation cycles during a 30-day period. (A cycle is one takeoff and one landing.) At the time of this study, the weight of the heaviest proposed Marine aircraft that would utilize SATS was 60,000 lb (27,000 lb per main gear wheel) with a 30-7.7, 18-ply tire inflated to 400 psi. For landing rollouts and taxi operations of the aircraft, the actual vertical load on the mat surface is assumed to equal the static load, or not to exceed 27,000 lb per main gear wheel. Present plans for assisted takeoffs incorporate a catapult system that will be installed on the mat surface. For this type of operation, the planes will take off from a fixed position on the mat, and for a given aircraft, the landing gear wheels will run in the same tracks on each takeoff. Also, a vertical load in addition to the static load of the plane will be applied during launching operations. For a 60,000-lb aircraft with 27,000-lb single-wheel static load, the Naval Air Engineering Laboratory (NAEL) has calculated that the effective single-wheel load on the mat during catapult launching will be about 39,000 lb.

Near the conclusion of these tests, NAEL notified WES that using a new type catapult for launching aircraft from the mat-surfaced runways, the main-gear wheel load is not expected to exceed 27,000 lb. This factor was considered in the analysis and conclusions (see paragraph 48a).

2. The aluminum landing mat used in the investigation was part of a production quantity fabricated by Butler Manufacturing Co., Kansas City, Mo.; it has been designated AM2 by the NAEL. The mat was designed by Harvey Aluminum, Inc., Torrance, Calif., and a small quantity fabricated by Harvey Aluminum was tested and reported earlier by the WES.*

Objectives and Scope of Investigation

3. The objectives of this study were to: (a) evaluate the performance of the Butler AM2 mat under accelerated traffic tests with the wheel loadings contemplated under the SATS concept, and (b) compare the performance of the Butler mat with that of the original experimental AM2 mat which was designed and fabricated by Harvey Aluminum.

4. The objectives were accomplished by:

a. Constructing a test section that consisted of different subgrade materials and strengths and surfacing the section with the Butler aluminum landing mat.

b. Performing accelerated traffic tests with 27,000- to 39,000-lb single-wheel loads and 400-psi tire inflation pressure.

c. Observing the behavior of mat and subgrades during traffic.

d. Analyzing the data obtained and comparing the data and the performance of the Butler mat during these tests with that of the Harvey aluminum mat during previous tests.

5. This report describes the landing mat, test section, tests, and results obtained and includes an analysis of the data and a comparison of performance of the mats fabricated by Butler and Harvey.

* U. S. Army Engineer Waterways Experiment Station, CE, Development of CBR Design Curves for Harvey Aluminum Landing Mat, Miscellaneous Paper No. 4-615 (Vicksburg, Miss., January 1964).

PART II: TEST SECTION, MAT, AND TEST LOAD CART

Test Section

Location

6. All traffic tests were conducted at the WES on a special test section which was constructed and tested under shelter in order to control tne subgrade water content and strength.

Description

7. A layout of the test section is shown in plate 1. The test section consisted of three items, each approximately 24 ft wide and 50 ft long. Items 1 and 2 were constructed of a heavy clay soil and item 3 was constructed of a loose sand.

Subgrade

8. Gradation and classification data for the subgrade materials used in the test section are shown in plate 2. The sand used in this investigation was obtained from a local river sandbar and its characteristics resembled those of a beach sand. It classified as SP according to the Unified Soil Classification System. The heavy clay soil (buckshot) had a liquid limit of 56 and a plasticity index of 33 and was classified as CH.

Construction of subgrade

9. Items 1 and 2. These items were to be constructed to a total thickness of 24 in.; therefore, the existing material at the test site was excavated to a depth of 24 in. below finished grade. It was desired to construct items 1 and 2 with the heavy clay soil at water contents that would result in CBR values of about 5 and 10, respectively, when compacted. The soil for each item was processed to the desired water content, hauled to the test section site by truck, spread, and compacted in 6-in. lifts. Compaction of items 1 and 2 was accomplished by applying eight coverages of a four-wheel rubber-tired roller loaded to 50,000 lb with tires inflated to 90 psi. The surface of each compacted lift was scarified prior to placement of the next lift. After placement and compaction of the fourth (final) lift, the surface of the subgrade was fine-bladed to grade with a motor patrol. Construction control data were obtained for each lift immediately after compaction.

10. Item 3. Item 3 of the test section consisted of uncompacted sand 24 in. deep that had been end-dumped from a truck and spread with a D4 tractor. A CBR of about 4 was measured in the sand item prior to placement of the mat. A CBR of 4 for a loose, unconfined sand has little meaning with respect to its strength because when confined, a sand develops a much higher strength. Photograph 1 shows the completed test section prior to placement of the mat.

Mat

Description

11. The Butler AM2 mat planks were made with a single extrusion. Full-size planks are 12.08 ft long and 2.06 ft wide, with average thickness of 1.50 in.; the average weight of a full plank is about 141 lb. Photograph 2 shows a full and a half plank with the end-connecting rod.

Placement procedures

12. The Butler mat was placed on the test section by a crew of six experienced laborers working under the supervision of a foreman. The mat bundles were placed alongside the test section by a forklift, and the laborers carried the individual mats about 30 ft into place. One laborer placed the end-connecting rods (photograph 3). No difficulties were encountered during the laying operation. The laying speed was approximately 340 sq ft per man-hour. This included opening the bundles, carrying the mat into position, and placing connecting rods.

13. The entire test section was surfaced with the mat placed perpendicular to the center line of the test section to provide a surfaced width of 24 ft (plate 1). Twenty-five runs of mat were used in surfacing each test item, or a total of 75 runs for the entire test section. The mat was laid with the end joints staggered by placing runs consisting of two whole planks adjacent to runs consisting of one whole and two half planks. Photograph 4 shows the completed test section prior to trafficking. This photograph also shows weights which were placed on the edges of the mat to prevent the edges from rising off the subgrade during traffic.

Test Load Cart

14. A specially designed single-wheel test cart (fig. 1) which can

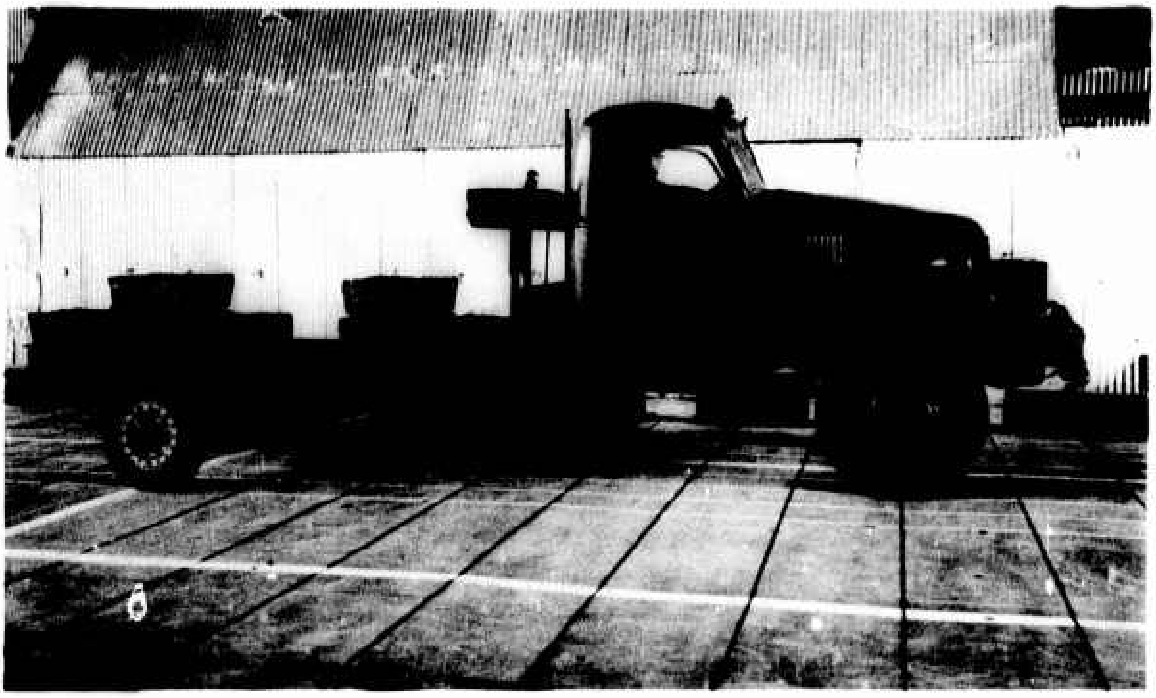

Fig. 1. Test load cart

be loaded to provide single-wheel loads up to 39.000 lb was used in the traffic tests. It was fitted with an outrigger wheel to prevent overturning and was powered by the front half of a four-wheel-drive truck. The load cart wheel was equipped with a 30-7.7. 18-ply tire. inflated to 400 psi. For the 27.000-lb load. the tire contact area was about 82 sq in. and the average contact pressure was 330 psi; for the 39,000-lb load, the tire contact area was about 103 sq in. and the average contact pressure was about 378 psi.

PART III: TESTS AND RESULTS

Traffic Tests

Uniform-coverage traffic

15. To simulate normal landing and takeoff operations or taxi operations on a taxiway, uniform-coverage traffic was applied over a 10-ft-wide traffic lane laid out down the center of the test section, as indicated in plate 1. Traffic was applied with the single-wheel test load cart loaded to 27,000 lb and tire inflated to 400 psi by driving the load cart first forward and then backward the length of the test section, shifting the path of the cart laterally about 7.3 in. (one tire-print width) on each successive forward pass. This procedure resulted in two complete coverages each time the load cart maneuvered from one side of the traffic lane to the other. Traffic was continued until mat failure developed or to a maximum of 188 coverages which has been established as being equivalent to 1600 cycles of operations for an aircraft having a 27,000-lb single-wheel load and 400-psi tire inflation pressure (see WES MP No. 4-615).

Single-track traffic

16. As explained in paragraph 1, if a catapult system is used for launching an aircraft on the mat-surfaced runway, the main gear wheels of a given type of aircraft will run in the same path during each takeoff and an added vertical load will be imposed on the mat in addition to the static load of the aircraft. It has been calculated that during the catapult launching of a 60.000-lb aircraft, this single-wheel load may be as much as 39,000 lb. To simulate 1600 cycles of such aircraft operations (in which 1600 launchings would be required), traffic was applied in a single path with the single-wheel test cart.

17. In accordance with instructions from the NAEL, the single-track traffic was initiated with 600 passes of a 27,000-lb single-wheel load and was to be followed by 600 passes of a 30,000-lb load, 300 passes of a 33.000-lb load. 300 passes of a 36,000-lb load, and finally, a sufficient number of passes of a 39,000-lb load to induce failure or to provide a total number of passes of the mixed loads that would be approximately

equivalent to 1600 passes of a 39,000-lb single-wheel load. By use of the CBR equation,* the proposed passes of the various wheel loads of less than 39,000 lb were converted to equivalent passes of a 39,000-lb wheel load. A summary of the proposed traffic-load schedule is given below.

Actual Load lb	Actual Passes of Test Load	Equivalent Passes of 39,000-lb Load	Equivalent Accumulative Passes of 39,000-lb Load
27,000	600	185	185
30,000	600	252	437
33,000	300	177	614
36,000	300	226	840
39,000	760	760	1600

This schedule of staggered loads was designed to provide more specific information on the load-carrying capabilities of the mat in the event that mat failure occurred prior to the end of the scheduled trafficking.

18. In the application of traffic, the load cart was driven forward and backward in the same track. The center line of the traffic path was located 2 ft outside the uniform-coverage traffic lane and 5 ft from the outside edge of the test section, as shown in plate 1. The traffic path was also about 1 ft from an end joint on every other run of mat.

Soils Tests and Miscellaneous Observations

19. Water content, density, and in-place CBR tests were conducted before and after traffic in each test item. Data obtained are summarized in tables 1 and 2 for the uniform-coverage traffic and the single-track traffic, respectively. In general, these tests were made at depths of 0, 6, 12, and 18 in. At least three tests were made at each depth, and the values listed in tables 1 and 2 are the averages of the values measured at each particular depth. It can be noted from tables 1 and 2 that the CBR values are reported to the nearest 0.1 CBR. Normally, CBR values are reported to the nearest whole number only which is about as accurate as

* U. S. Army Engineer Waterways Experiment Station, CE, Developing a Set of CBR Design Curves, Instruction Report No. 4 (Vicksburg, Miss., November 1959).

the effective CBR values can be measured in the field. However, when evaluating the service life of landing mats placed over low-strength subgrade, CBR values are reported in terms of fractions since rounding off these values could result in significant variations in the resultant service life of the mat.

20. Visual observations of the behavior of the test items and other pertinent factors were recorded throughout the traffic testing period. These observations were supplemented by photographs. Level readings were taken prior to and at intervals during traffic to show the development of roughness and permanent deformation and deflection of the mat under the wheel load.

Behavior of Mat Under Traffic

Failure criteria

21. The failure criteria used for the Butler mat were the same as those used for the original Harvey mat and were based on the following excessive mat breakage: (a) end-joint failures, (b) core failures, and (c) elastic mat deflection (1-in. maximum).

22. It was assumed that a certain amount of maintenance would be performed in the field during actual usage and that short weld breaks, overlapping corner breaks, etc., could be repaired rather easily. However, when an end-connector joint sheared off or a mat core failed completely, the mat plank would be considered failed and should be replaced. Partial core failures did not result in an unserviceable plank, but in some cases, the failures progressed to the point where the plank was considered unserviceable. It was considered feasible to replace up to 10 percent of the mat with new planks during the design service life of the runway. For replacement of more than 10 percent of the planks, the maintenance effort would be excessive. Therefore, for the test section, it was assumed that up to 10 percent of the mat planks could be replaced; when an additional 10 percent (a total of 20 percent) of the planks failed, the entire item was considered failed.

23. The criterion of 1-in. maximum deflection is based on previous experience in mat testing in which it was observed that mat deflections in excess of 1 in. cause the mat to break up at a rapid rate

and also create a high rolling resistance.

24. The degree of roughness is also normally used in judging failures; however, it was not pertinent in this study since the surface remained quite smooth throughout the period of traffic, except where mat failure occurred.

27,000-lb uniform-coverage traffic

25. Mat performance. Mat breakage was first noted in item 1 after 12 coverages of traffic. The breaks were small hairline cracks between the end-connector weld and the end of the extruded portion of the plank. These breaks generally started at the overlapping edge of a plank and progressed with traffic across the full width of the plank. The first end joint sheared off completely at 36 coverages, and by the end of 50 coverages, seven end-joint failures had occurred. Photograph 5 shows the start of one of these cracks and photograph 6 shows an end joint sheared off completely. A total of 72 coverages were made on item 1. Considerable flexing of the mat was evident throughout the trafficking, although the surface remained generally smooth, as can be seen in photograph 7 which shows item 1 at the conclusion of traffic.

26. The same progressive type end-joint failures noted in item 1 occurred in item 2. The first sheared end joint occurred at 100 coverages, and seven more of these failures were noted by the end of 120 coverages of traffic. Photograph 8 shows a sheared end joint with a small tear in the top skin at 150 coverages when traffic was stopped. Several top skin tears were noted, but their occurrence followed the failure of the end joint. A general view of item 2 after 150 coverages is seen in photograph 9. As indicated by the uneven traffic lines in photograph 9, a considerable amount of lateral shifting of the mat occurred during trafficking.

27. Item 3 sustained the full 188 coverages of the 27,000-lb traffic with no mat damage, as seen in photograph 10. When the mat was removed at the end of trafficking, it was found that the sand had consolidated and the mat was bridging 2-3 in. over the subgrade. This resulted in high mat deflections as the load wheel passed over the mat. In spite of the flexing caused by this condition, the mat remained in excellent condition throughout the trafficking period.

28. Permanent deformation. Plots showing permanent deformation of

the mat as determined from level readings taken prior to and at the end of uniform-coverage traffic are shown in plate 3. Since the mat was laid in a staggered pattern, every other run of mat consisted of two whole planks with an end joint located on the center line of the traffic lane. The adjacent runs consisted of two half planks, one on each side of the lane, with a whole panel in the center so that the center of the plank was located on the center line of the traffic lane. Plate 3 shows average cross sections for both conditions for each item of the test lane. These data indicate that the deformation across the traffic lane was generally about the same, regardless of where the joint was located. From plate 3 it can also be noted that the permanent deformation was about the same in all three items and did not exceed 1/2 in.

29. Center-line profiles illustrating deformation of the mat down the center of each test item are shown in plate 4. These profiles show slight deviations in deformation among the test items. However, the surface remained quite smooth throughout the traffic period, particularly in item 3. Most of the abrupt deviations in elevation in items 1 and 2 are due to end-joint failures in mat planks.

30. Elastic deflection. Deflections of the mat surface under load, as determined from level readings, are shown in plate 5 and indicate the elastic deflection, or rebound, of the mat as the wheel load moved over the surface. Deflections are shown for two mat plank locations in each test item, i.e. at an end joint and at the center point of a plank. Data are shown for deflections at the start of traffic and at the end of traffic on each test item. From these data, no consistent difference is apparent in mat deflection in relation to the point of load, i.e. on the joint or center of plank. The magnitude of the deflection was about the same in items 1 and 2, and no noticeable change in deflection values occurred as traffic progressed in these items. Item 3 had considerably higher deflections as traffic continued due to the densification of the sand and the resultant bridging action of the mat. The maximum deflection at the end of traffic was about 2.0 in. The AM2 mat had sufficient flexibility to withstand the high deflections without excessive breakage; therefore, the performance of the mat over the loose sand item is considered satisfactory. However, the high deflections are not desirable and could be

eliminated by compacting the sand prior to laying the mat.

Single-track traffic

31. As stated previously, the single-track traffic was applied with a range of specific single-wheel loads which were to vary from 27,000 to 39,000 lb. The behavior of the mat under the various wheel loads is discussed in the following paragraphs.

32. 27,000-lb load. A total of 600 passes of the 27,000-lb single-wheel load applied in a single path resulted in no apparent damage to the mat in any of the test items. There was no mat breakage, and the surface remained smooth throughout this phase of traffic.

33. 30,000-lb load. After 120 passes of the 30,000-lb load, three planks in item 1 had slight depressions, and by the end of 200 passes, 10 planks in item 1 had severe depressions. These depressions indicated that the mat core was shearing and collapsing under the load. Photograph 11 shows item 1 after 470 passes of the 30,000-lb load. Traffic was stopped at this point with 19 planks indicating core failures. The mat in items 2 and 3 remained in excellent condition through 600 passes of the 30,000-lb load.

34. 33,000-lb load. Slight depressions occurred in two planks in item 2 after 100 passes of the 33,000-lb load. One of these planks was removed after 150 passes and sawed through the depressed area. Fig. 2 shows

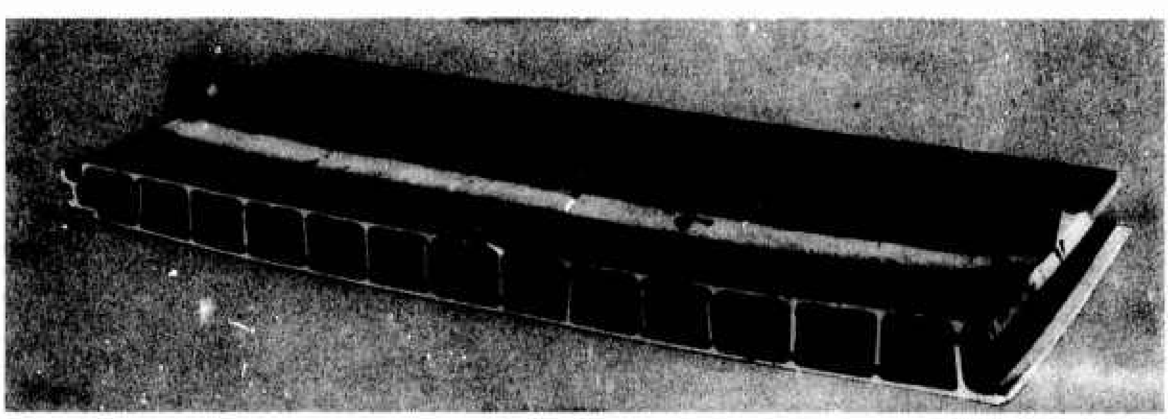

Fig. 2. Core failure in item 2 after 150 passes of 33,000-lb single-wheel load

the sheared members of the core. By the end of 200 passes of the load wheel on item 2, six additional core failures had occurred, and after

300 passes, 18 planks had core failures and traffic was stopped. Photograph 12 shows a general view of item 2 after 300 passes of traffic.

35. After 300 passes of the 33,000-lb load on item 3, four planks had slight depressions which indicated core failure and traffic was stopped at this point in accordance with instructions from an NAEL representative. Photograph 13 shows a general view of item 3 at the conclusion of trafficking.

Summary and Analysis of Test Results

Uniform-coverage traffic

36. A summary of the test results for the 27,000-lb single-wheel load traffic applied uniformly over the 10-ft-wide traffic lane is shown in table 3 which presents the rated subgrade CBR and data on mat breakage and deflection at various stages of traffic. The last column in table 3 indicates the rating of the test item, based on the failure criteria described in paragraphs 21-24.

37. The rated CBR for the clay subgrades, items 1 and 2, is based on the numerical average of the CBR values at 0-, 6-, and 12-in. depths prior to and after traffic (table 1). The sand in item 3 had an initial CBR of 4.2, but the value increased considerably to about 26 during the traffic period, as shown in table 1. The bridging and severe mat deflection, as discussed previously for this item, were due to densification of the sand during traffic. The initial CBR value is a relative measure of the degree of density in a sand, and the lower the initial CBR value, the more settlement can be anticipated. No specific rated CBR was assigned, but it is known that, due to the mat behavior, an effective CBR greater than 7.7 (rated CBR for item 2) must have been present.

38. As can be noted in table 3, item 1 was considered failed at 50 coverages and item 2 at 120 coverages. Both of these failure-coverage levels were assigned when the number of sheared end joints reached 20 percent of the number of planks in the traffic lane in accordance with the failure criteria discussed earlier. The mat in item 3 was considered satisfactory for the full 188 coverages of the 27,000-lb single-wheel load, even though elastic mat deflections of greater than 1 in. occurred. These

high deflections did not appear to be detrimental to the mat structure, but might be objectionable from the standpoint of aircraft performance.

Single-track traffic

39. Table 4 presents a summary of the test results for the 27,000- through 33,000-lb single-wheel load traffic applied in a single track. The rated subgrade CBR values were derived from the data in table 2 in the same manner as those for the uniform-coverage traffic lane, as discussed in paragraph 37. The indicated core failures are based on observations of the plank which was sawed through. From these observations, it was determined that when a depression of 0.2 in. or more developed in a mat plank, one or more core members failed. The maximum elastic deflection at two different locations on the mat is also given in table 4. The traffic path was located so that for every other mat run, the load wheel passed over a 6-ft-long half mat plank 1 ft from the end joint. For the runs composed of two whole planks, the load wheel passed over a whole plank 5 ft from the edge or 1 ft from the center of the plank. The maximum deflections at these two points are given in table 4.

40. The high percentage of core failures under the 30,000- and 33,000-lb single-wheel loads in all test items indicates that the mat core is not adequate to support a 39,000-lb load for 1600 passes in a single track, regardless of subgrade strength.

41. As mentioned in paragraph 1, a new type of catapult is now being considered for launching aircraft from the mat-surfaced runways. For this new system, NAEL does not expect the main-gear wheel load to exceed 27,000 lb during the launching operation. Evidence has been developed in accelerated traffic tests on pavements, landing mats, and unsurfaced soils to indicate that a given number of coverages of a specific wheel load and tire pressure applied in a single track is not as severe as the same number of coverages applied over several track widths. In this study, the initial 600 passes, or coverages, of traffic with 27,000-lb single-wheel load applied in a single track resulted in no apparent damage to the mat in any of the test items, whereas the mat in test item 1 was considered failed due to mat breakage (mostly end-joint failures) by the end of 50 coverages of traffic with 27,000-lb single-wheel load distributed uniformly over a 10-ft width. Therefore, a subgrade

strength which is adequate (when the subgrade is surfaced with AM2 landing mat) to support 188 coverages of a 27,000-lb single-wheel load distributed over a 10-ft width will also be adequate to support 1600 passes (or coverages) of the same wheel load when applied in a single track.

PART IV: DEVELOPMENT OF CBR DESIGN CURVES

42. Using the technique described in Miscellaneous Paper No. 4-615, referenced in paragraph 2, CBR design curves were developed for the Butler mat. A plot of CBR versus coverages for the 27,000-lb single-wheel-load traffic is shown in plate 6. The points plotted are the rated CBR values listed in table 3 and the corresponding number of coverages at failure. Failure developed on the subgrade with a rated CBR of 5.2 at about 50 coverages and on the subgrade with a rated CBR of 7.7 at about 120 coverages. Using the CBR equation as described in Miscellaneous Paper No. 4-615, the Butler mat was found to require a CBR of 8.8 to support 188 coverages.

43. Plate 7 shows a CBR design curve for 188 coverages of a 27,000-lb single-wheel load with a tire pressure of 400 psi. The lower curve is a standard flexible pavement CBR design curve. The design curve for the Harvey mat, included in plate 7 for comparison, was obtained from plate 8 of Miscellaneous Paper No. 4-615. The curve for the Butler mat was developed using the same technique as that described for the Harvey mat.

44. A plot of CBR values from table 4 versus calculated equivalent passes of a 39,000-lb single-wheel load at 400-psi tire pressure is shown in plate 8. Failure developed on the subgrade with a rated CBR of 5.7 at about 269 passes and on the subgrade with a rated CBR of 8.8 at about 555 passes. Using the technique described in Miscellaneous Paper No. 4-615, the failure point plotted at 8.8 CBR and 555 passes was translated in plate 8 to a CBR of 10.9 at 1600 passes.

45. A CBR design curve for 1600 passes of a 39,000-lb single-wheel load with a 400-psi tire inflation pressure for the Butler mat is shown in plate 9. This curve was developed, using the data in plate 8, in the same manner as that described in Miscellaneous Paper No. 4-615 for the Harvey aluminum landing mat.

PART V: PERFORMANCE COMPARISONS OF BUTLER AND HARVEY AM2 LANDING MAT

46. As can be seen from the CBR design curves, the performance of the Butler mat was not as good as that of the Harvey mat. The greatest difference in performance of the mat appeared to be in the welds at the end connectors. For example, in table 3 of the Harvey mat report, it can be noted that only one end-joint weld failure occurred in test item 1 (which had a rated subgrade CBR of 7.7) during the application of 188 coverages of 27,000-lb single-wheel-load traffic, whereas in the test on the Butler mat, a total of 12 end-joint failures occurred in test item 2 (which had a rated CBR of 7.7) during the application of 150 coverages of traffic with the same wheel load. In addition, there were cracks in the welds of all other mat planks within the traffic lane.

47. In the Harvey mat tests, it was concluded that the mat core design was borderline in ability to sustain 1600 passes of a 39,000-lb single-wheel load with a tire inflation pressure of 400 psi applied in a single path, regardless of subgrade strength. It can be seen in table 4 that the Butler mat in item 2 (rated CBR of 8.8) had 18 planks fail due to core failures after 300 passes of the 33,000-lb single-wheel load (equivalent to 614 accumulative passes of the 39,000-lb load). The Harvey mat on a rated CBR of 6.5 sustained the same amount of traffic with only two plank failures and these were due to sheared end joints rather than to core failures. It should be pointed out, however, that at this stage of traffic, the Harvey mat also had six planks with indicated core failures, although they were not severe enough to rate the planks as failed. Thus, it is apparent that the core of the Butler mat is not quite as strong as that of the Harvey mat.

PART VI: CONCLUSIONS

48. The following conclusions are drawn from the data presented in this report:

- a. Although the performance of the Butler AM2 mat was not as good as the original Harvey mat, the test data indicate that the Butler mat will sustain 1600 cycles (188 coverages) of aircraft operations of a 60,000-lb aircraft with a 27,000-lb single-wheel load and tire inflation pressure of 400 psi when placed on a subgrade having a CBR of 8.8 or greater throughout the period of traffic as compared to a required CBR of 6.3 for the Harvey aluminum mat. This conclusion includes catapult launchings in which the vertical load on a single wheel will not exceed 27,000 lb during the launching operations.

- b. Based on the equivalent wheel-load concept described in this report and ignoring the deficiencies of the mat core, the Butler aluminum mat will sustain 1600 passes of a 39,000-lb single-wheel load with tire inflation pressure of 400 psi applied in a single path when placed on a subgrade having a CBR of 10.9 or greater throughout the period of traffic as compared to a required CBR of 7.4 for the Harvey aluminum mat. However, based on the mat core failures that occurred during the single-track traffic with 33,000-lb single-wheel load (see paragraphs 40 and 47), it is concluded that the mat core is inadequate to sustain 1600 passes of a 39,000-lb single-wheel load with tire inflation pressure of 400 psi applied in a single path, regardless of subgrade strength.

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Table 1

Summary of CBR, Density, and Water Content Data for Uniform-Coverage Traffic*

		Before Traffic				After Traffic				
Test Item	Subgrade Material	Depth in.	CBR	Water Content %	Dry Density lb/cu ft	Depth in.	CBR	Water Content, %	Dry Density lb/cu ft	Mat Performance
1	Clay	0	4.2	25.2	96.2	0	5.0	26.5	--	Failed at 50 coverages
		6	4.2	26.0	95.9	2	6.3	24.7	97.0	
		12	5.0	24.1	95.7	6	6.5	24.2	97.5	
		18	4.2	25.2	95.9	12	6.4	25.0	96.0	
						18	4.4	26.3	93.5	
2	Clay	0	7.3	22.0	99.1	0	6.5	25.5	--	Failed at 120 coverages
		6	10.3	21.7	98.7	2	7.9	24.2	99.1	
		12	6.7	23.6	97.5	6	8.0	23.7	97.7	
		18	7.0	23.3	97.6	12	7.4	24.5	98.0	
						18	10.4	23.1	98.5	
3	Sand	0	2.1	2.4	98.2	0	25.0	3.0	--	Satisfactory for 188 coverages
		6	5.9	2.9	100.6	2	30.0	2.6	106.8	
		12	4.7	2.8	95.7	6	27.0	2.9	103.7	
		18	2.9	2.8	96.0	12	25.0	3.1	99.1	
						18	15.0	2.6	102.3	

Note: Traffic was applied using 27.000-lb single-wheel load and 400-psi tire pressure.
* All values tabulated are averages of three or more tests.

Table 2

Summary of CBR, Density, and Water Content Data for Single-Track Traffic*

Test Item	Subgrade Material	Before Traffic Depth in.	Before Traffic CBR	Before Traffic Water Content %	Before Traffic Dry Density lb/cu ft	After Indicated Traffic Period Wheel Load lb	After Indicated Traffic Period No. Passes	After Indicated Traffic Period Depth in.	After Indicated Traffic Period CBR	After Indicated Traffic Period Water Content %	After Indicated Traffic Period Dry Density lb/cu ft	Mat Performance
1	Clay	0	7.3	24.2	97.6	30,000	470	0	3.9	26.9	---	Failed at 269 equivalent passes of 39,000-lb load
		6	6.3	24.1	97.6			2	5.6	24.3	96.5	
		12	5.7	26.3	96.3			6	4.1	25.9	97.1	
		18	5.7	25.6	96.7			12	6.7	23.5	98.5	
								18	5.2	24.2	97.0	
2	Clay	0	8.3	24.1	98.8	33,000	300	0	6.3	25.2	---	Failed at 555 equivalent passes of 39,000-lb load
		6	10.0	23.0	99.5			2	6.7	24.6	98.9	
		12	9.0	24.5	97.3			6	8.7	24.0	100.3	
		18	8.6	24.1	96.0			12	10.3	22.9	99.4	
								18	12.0	22.5	99.4	
3	Sand	0	9.5	3.3	99.3	33,000	300	0	25.0	2.9	---	Traffic stopped at 614 equivalent passes of 39,000-lb load. Four planks failed
		6	16.0	2.9	99.9			2	32.0	2.8	103.0	
		12	8.7	2.9	100.5			6	35.0	3.2	102.1	
		18	6.0	2.8	100.2			12	20.0	3.2	99.2	
								18	16.0	3.3	97.9	

Note: Traffic was applied using 27,000- through 33,000-lb single-wheel loads and 400-psi tire pressure.
* All values tabulated are averages of three or more tests.

Table 3

Summary of Traffic Test Results for Uniform-Coverage Traffic

Test Item	Subgrade Material	Subgrade Rated CBR*	No. Panels in Traffic Lane	Traffic Coverages	Mat Breakage: End-Joint Weld Break: Over-lapping	Mat Breakage: End-Joint Weld Break: Under-lapping	Mat Breakage: End Joint Sheared: Over-lapping	Mat Breakage: End Joint Sheared: Under-lapping	Maximum Mat Deflection, in.: Center Point of Plank	Maximum Mat Deflection, in.: Joint	Rating of Item
1	Clay	5.2	37	0	0	0	0	0	0.7	0.7	
				20	4	1	0	0	0.7	0.7	
				50	7	8	3	4	0.7	0.7	Failed at 50 coverages due
				72	10	12	7	6	0.8	0.8	to excessive mat breakage
2	Clay	7.7	37	0	0	0	0	0	0.4	0.5	
				20	1	0	0	0	0.4	0.5	
				50	1	3	0	0	0.5	0.6	
				100	3	9	2	0	0.5	0.6	Failed at 120 coverages due
				150	12	13	6	6	0.5	0.6	to excessive mat breakage
3	Sand	---	38	0					0.2	0.2	
				20	0	0	0	0	1.1	1.2	
				50	0	0	0	0	1.4	1.6	
				100	0	0	0	0	1.8	2.0	
				188	0	0	0	0	2.0	2.1	Satisfactory for 188 coverages

Note: Traffic was applied using 27,000-lb single-wheel load and 400-psi tire pressure.
* Rated subgrade CBR values represent the average values for 0-, 6-, and 12-in. depths before and after traffic (see table 1).

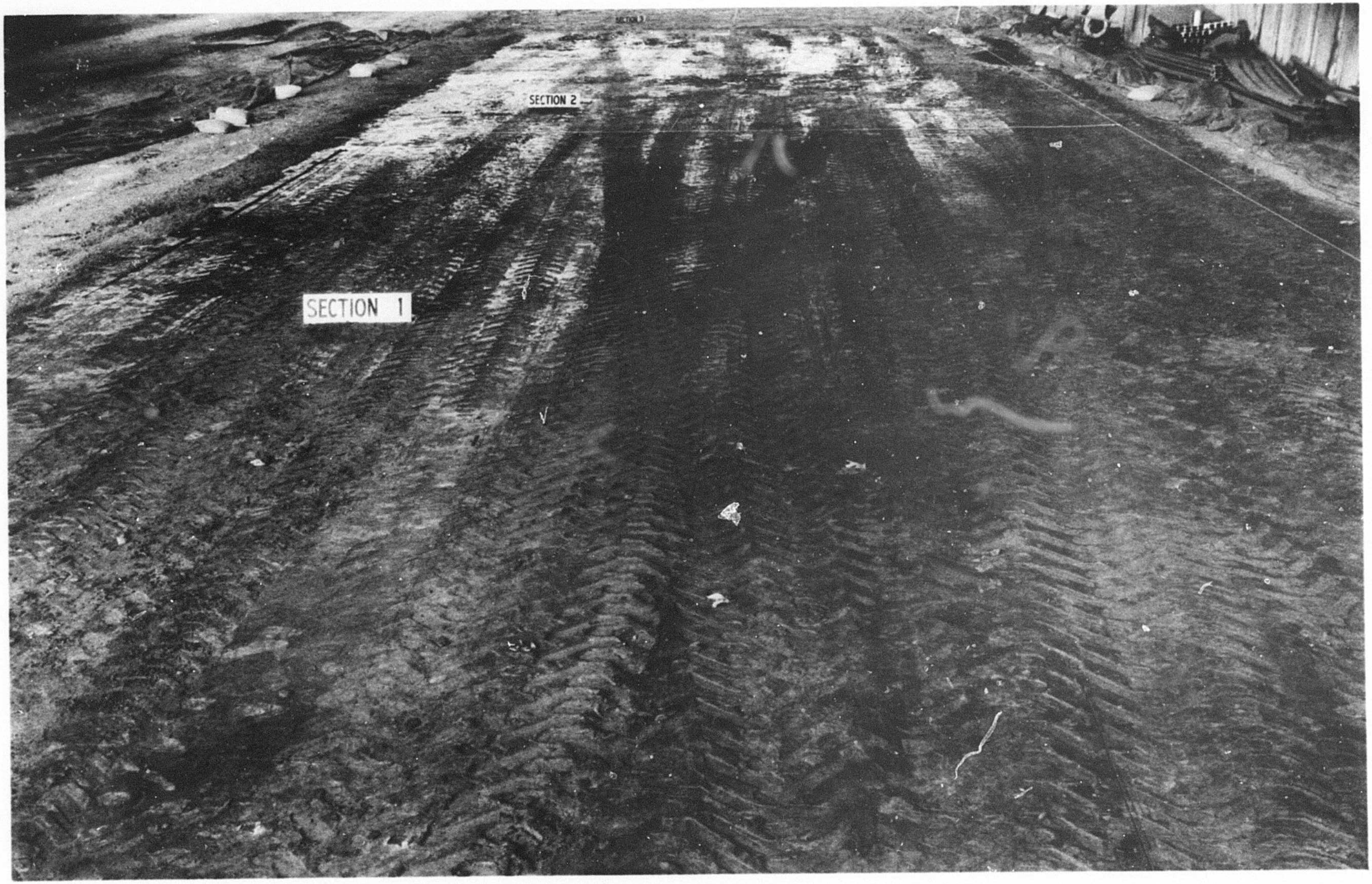
Table 4

Summary of Traffic Test Results for Single-Track Traffic

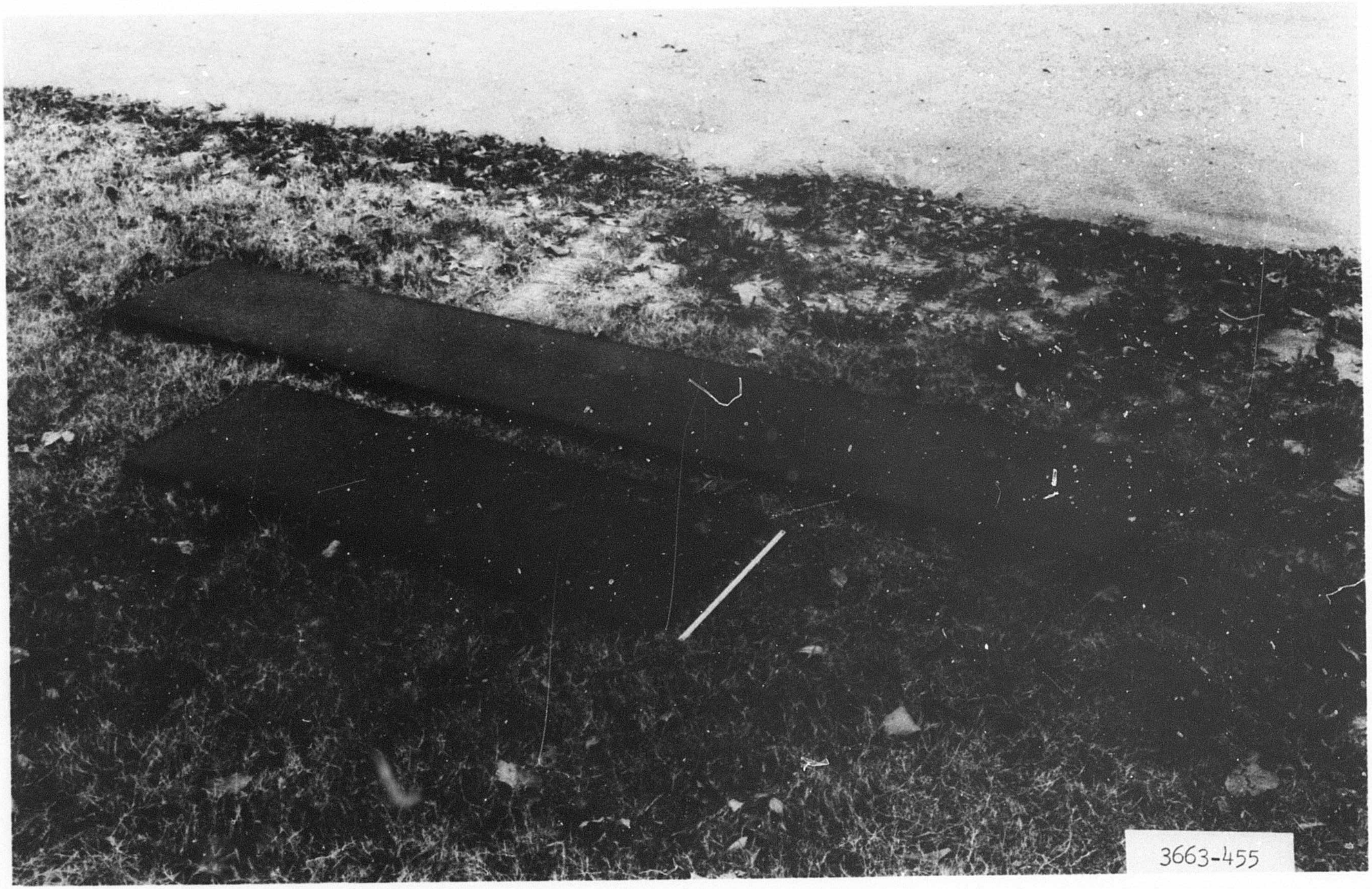
Test Item	Subgrade Material	Subgrade Rated CBR*	No. Panels in Item	Traffic Single-Wheel Load, lb	Traffic Actual Passes of Test Load	Equivalent Accumulated Passes of 39,000-lb Load	Mat Breakage End-Joint Weld Failures	Mat Breakage Planks with Indicated Core Failures	Planks Failed	Maximum Mat Deflection, in. 1 ft from Joint	Maximum Mat Deflection, in. 1 ft from Center	Rating of Item
1	Clay	5.7	25	27,000	0	0	0	0	0	0.60	0.60	
				27,000	600	185	0	0	0	0.75	0.70	
				30,000	470	387	0	19	19	0.95	0.70	Failed at 200 passes of 30,000-lb load. (Equivalent to 269 accumulated passes of 39,000-lb load.)
2	Clay	8.8	25	27,000	0	0	0	0	0	0.30	0.30	
				27,000	600	185	0	0	0	0.25	0.30	
				30,000	600	437	0	0	0	0.35	0.40	
				33,000	300	614	0	18	18	0.40	0.45	Failed at 200 passes of 33,000-lb load. (Equivalent to 555 accumulated passes of 39,000-lb load.)
3	Sand	---	25	27,000	0	0	0	0	0	0.30	0.25	
				27,000	600	185	0	0	0	0.70	0.55	
				30,000	600	437	0	0	0	0.70	0.60	
				33,000	300	614	0	4	4	0.55	0.55	Approaching failure after 300 passes of 33,000-lb load. (Equivalent to 614 accumulated passes of 39,000-lb load.)

Note: Traffic was applied using 27,000- through 33,000-lb single-wheel loads and 400-psi tire pressure.

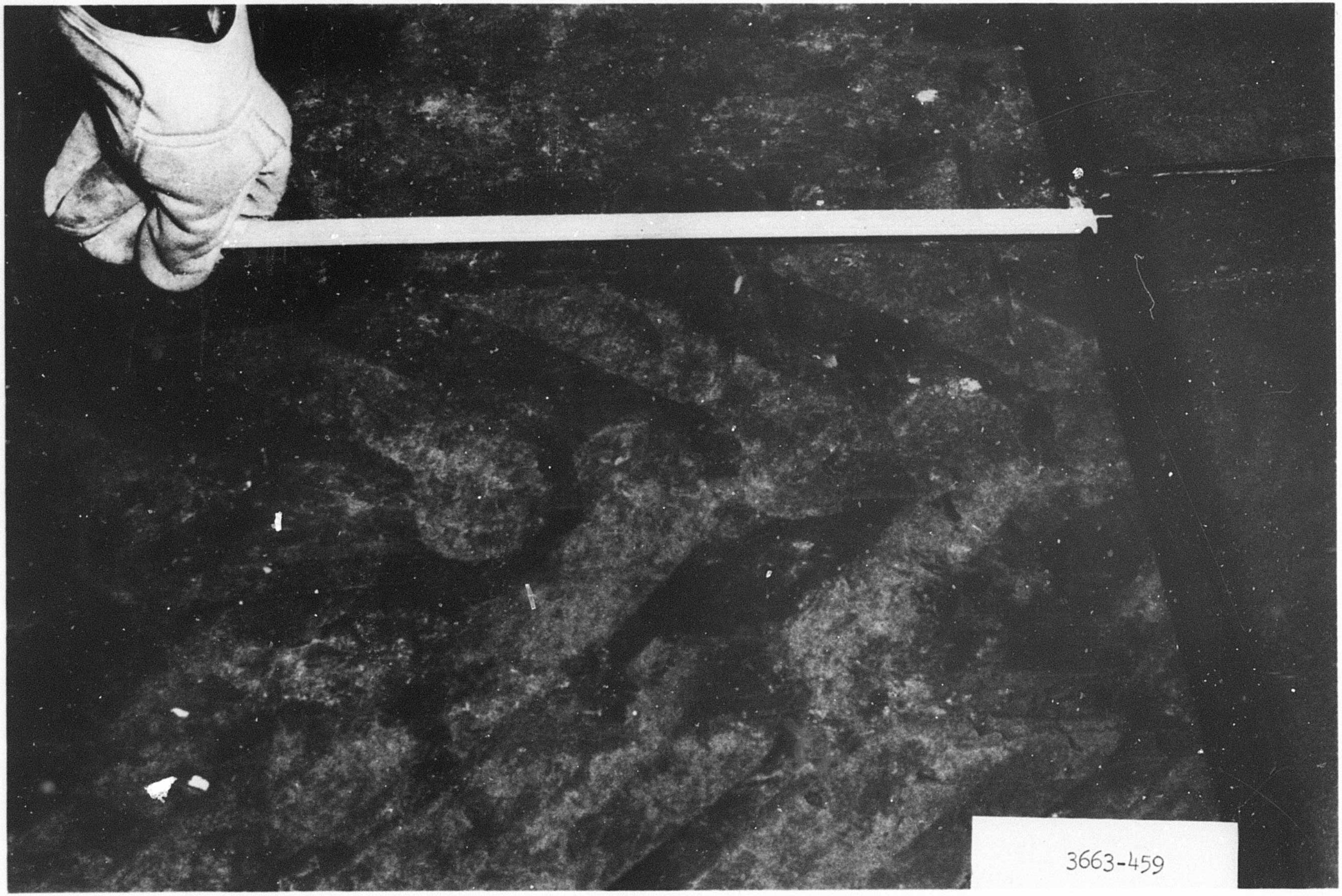
* Rated subgrade CBR values represent the average values for 0-, 6-, and 12-in. depths before and after traffic (see table 2).



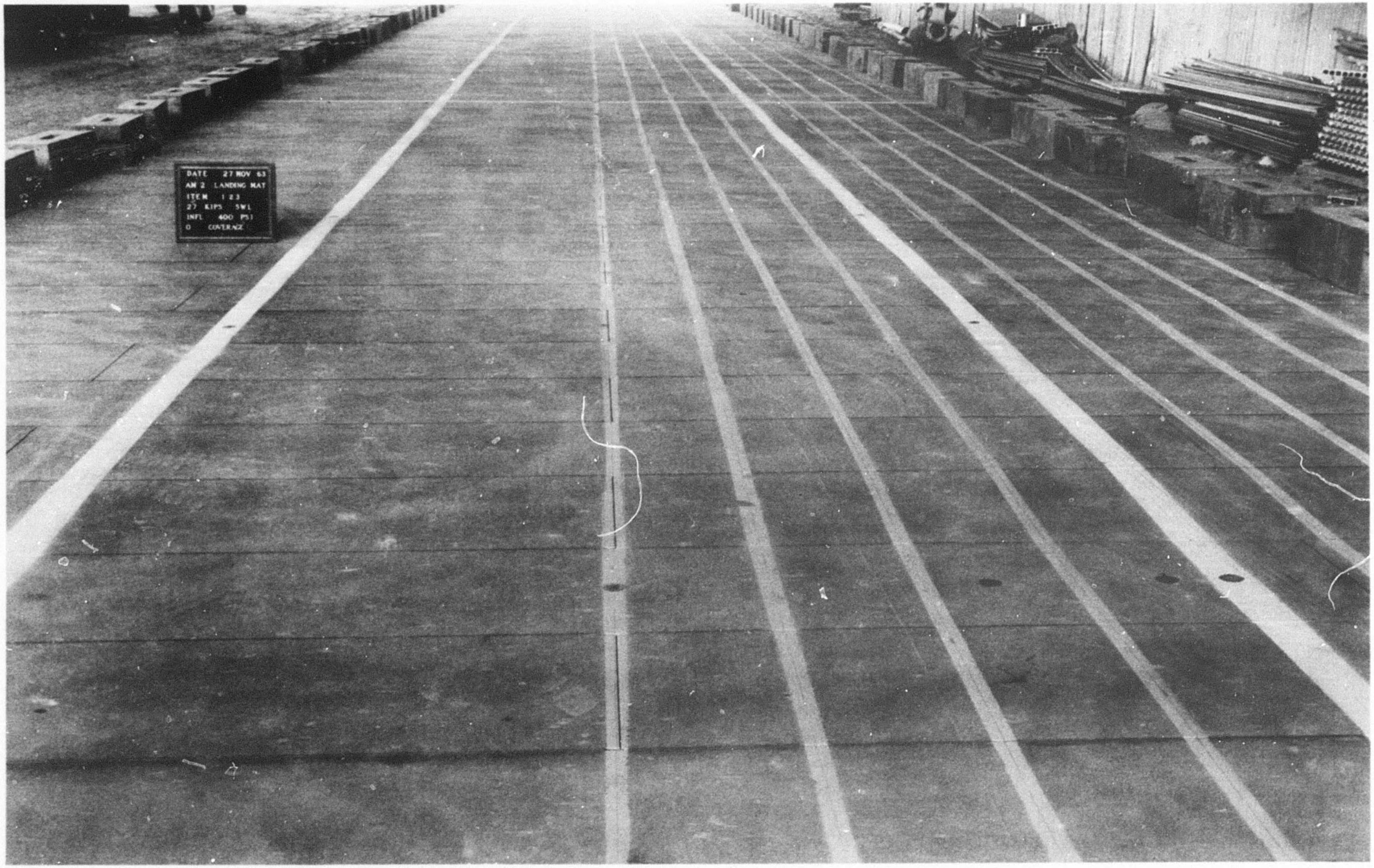
Photograph 1. Completed test section prior to mat placement



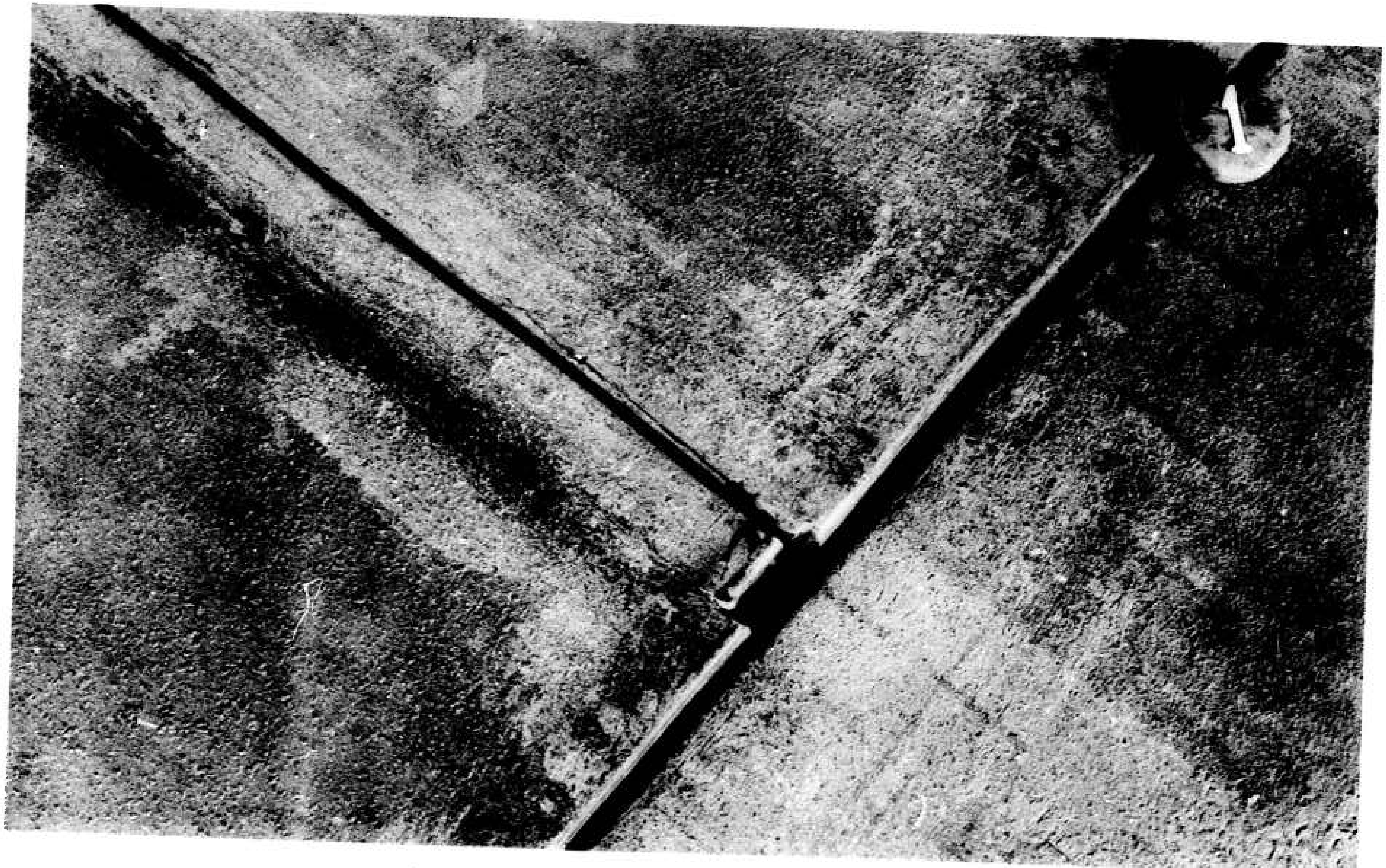
Photograph 2. Full and half panel of Butler AM2 mat with end-connecting rod



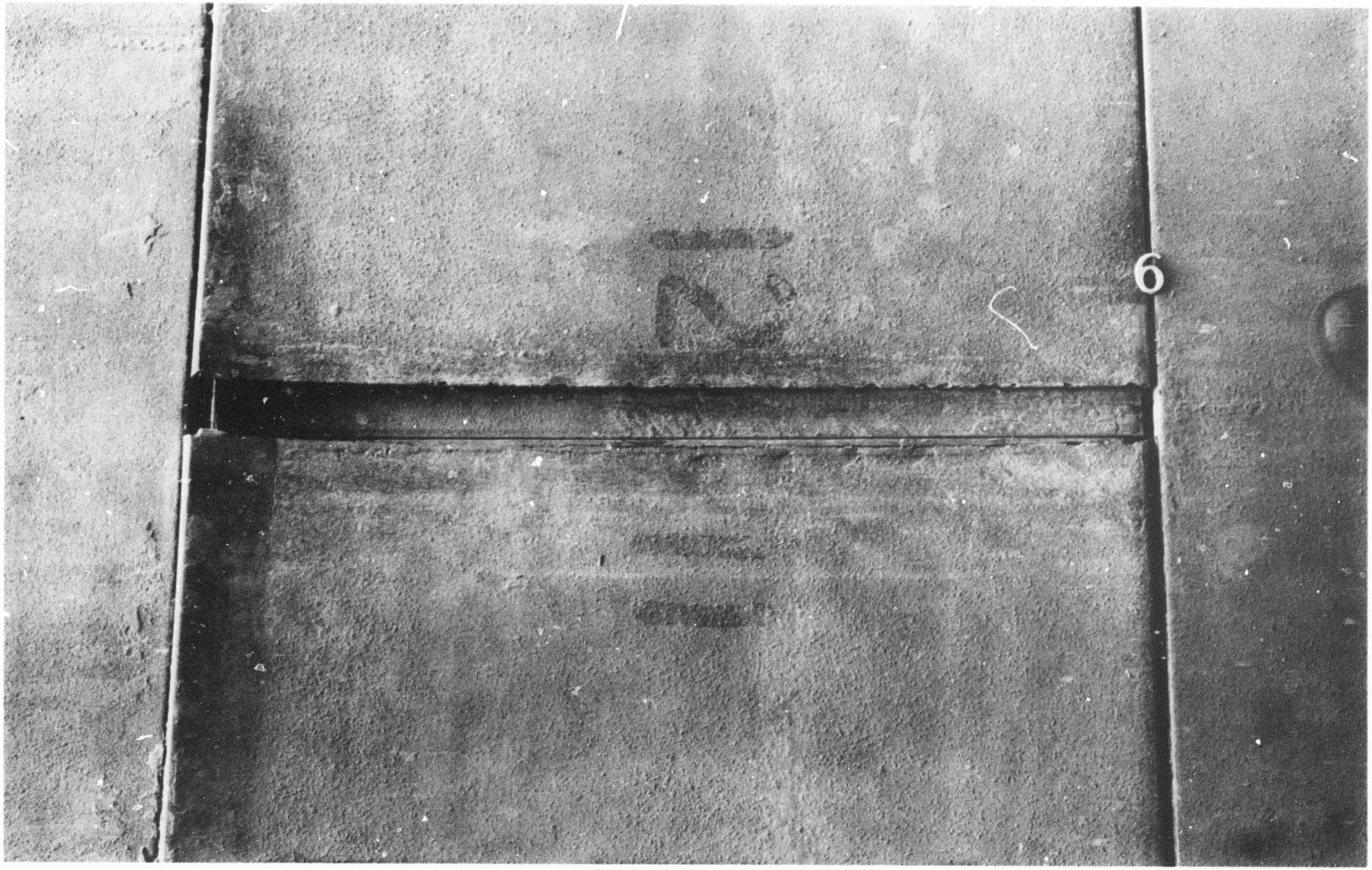
Photograph 3. Placing end-connecting rods



Photograph 4. Completed test section prior to traffic



Photograph 5. Start of crack in end-joint weld



Photograph 6. Sheared end joint

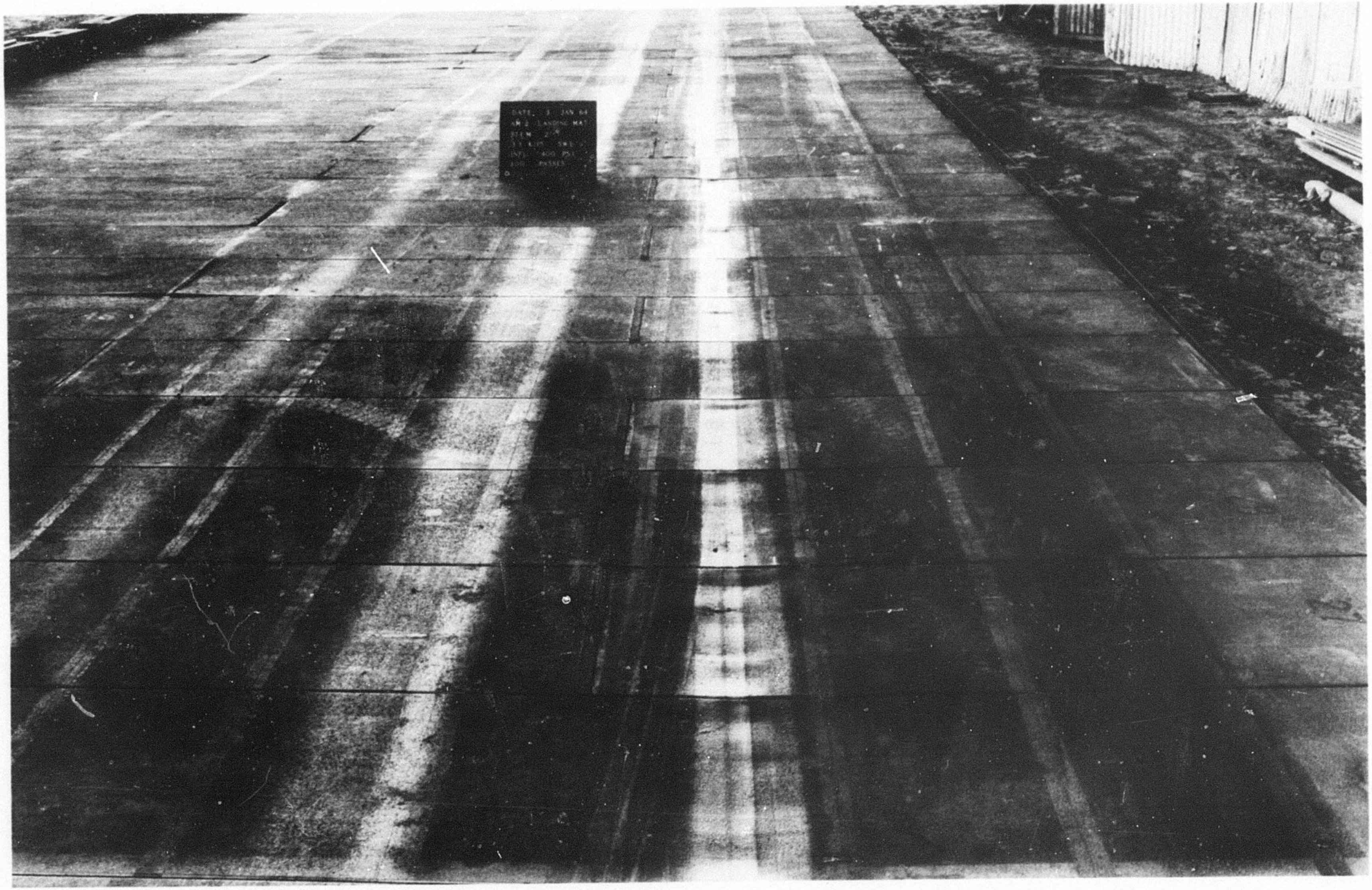
Photograph 7. Item 1 after 72 coverages of 27,000-lb single-wheel load

Photograph 8. Sheared end joint in item 2 after 150 coverages of 27,000-lb single-wheel load

Photograph 9. Item 2 after 150 coverages of 27,000-lb single-wheel load

Photograph 9. Item 2 after 150 coverages of 27,000-lb single-wheel load

Photograph 11. Item 1 after 470 passes of 30,000-lb single-wheel load



Photograph 12. Item 2 after 300 passes of 33,000-lb single-wheel load

Photograph 13. Item 3 after 300 passes of 33,000-lb single-wheel load

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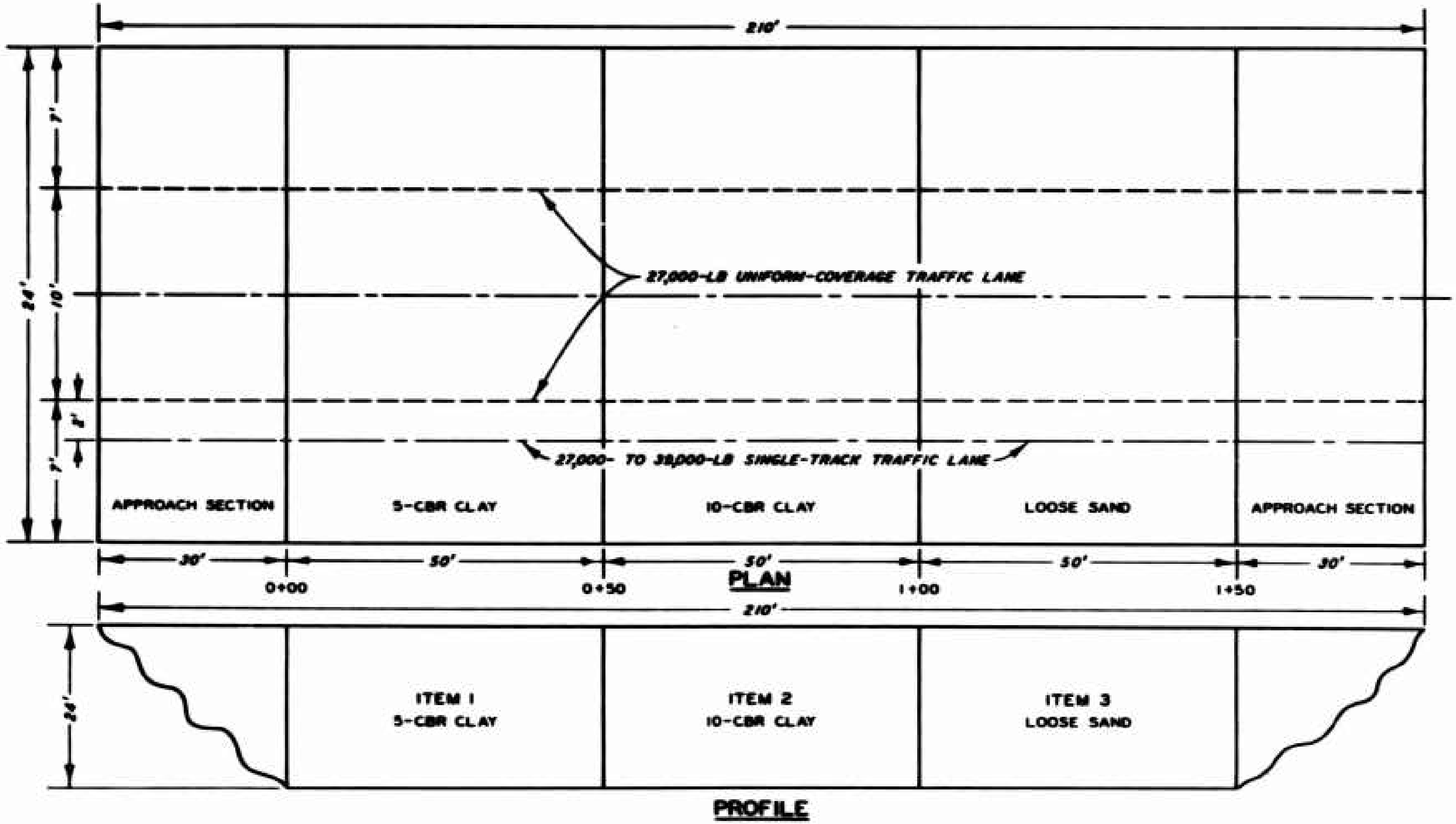
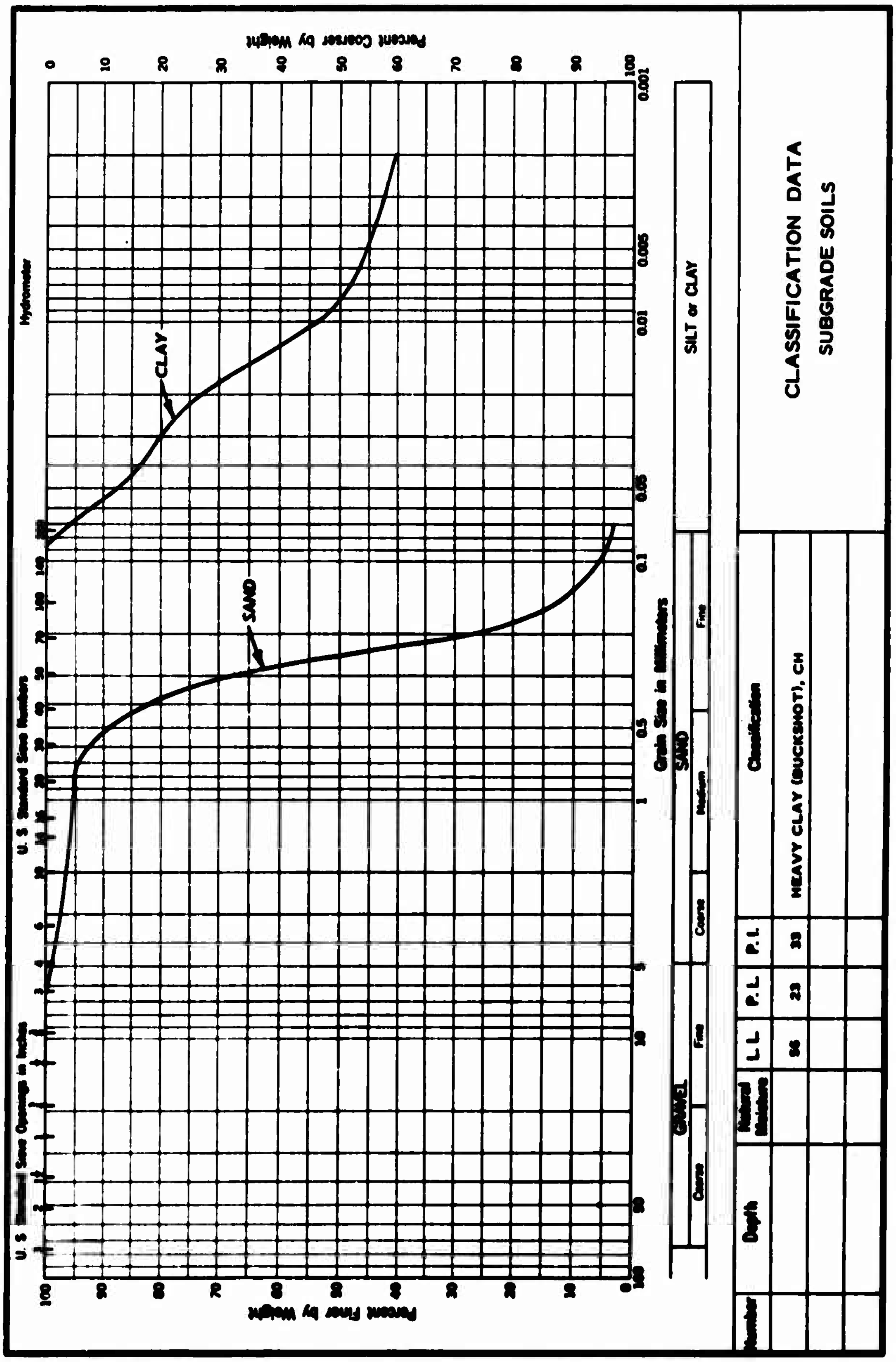


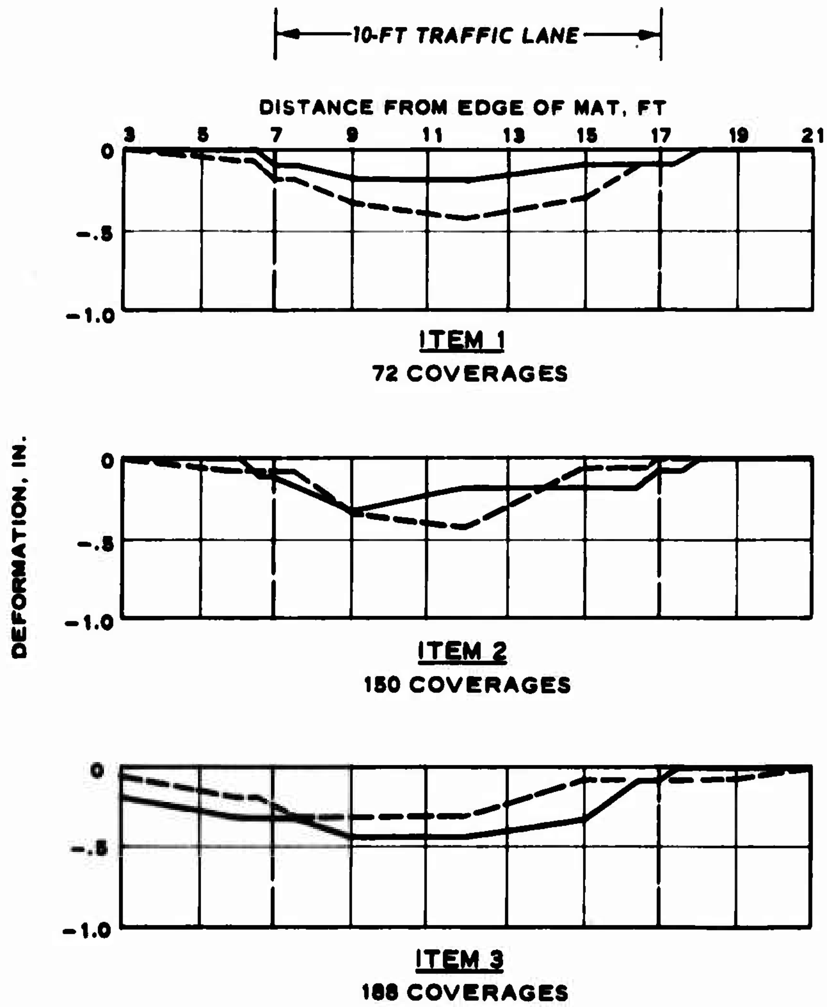
TEST SECTION LAYOUT

PLATE 1



Number	Depth	Natural Moisture	L.L	P.L	P.I.	Classification
			56	23	33	HEAVY CLAY (BUCKSHOT), CH

PLATE 2

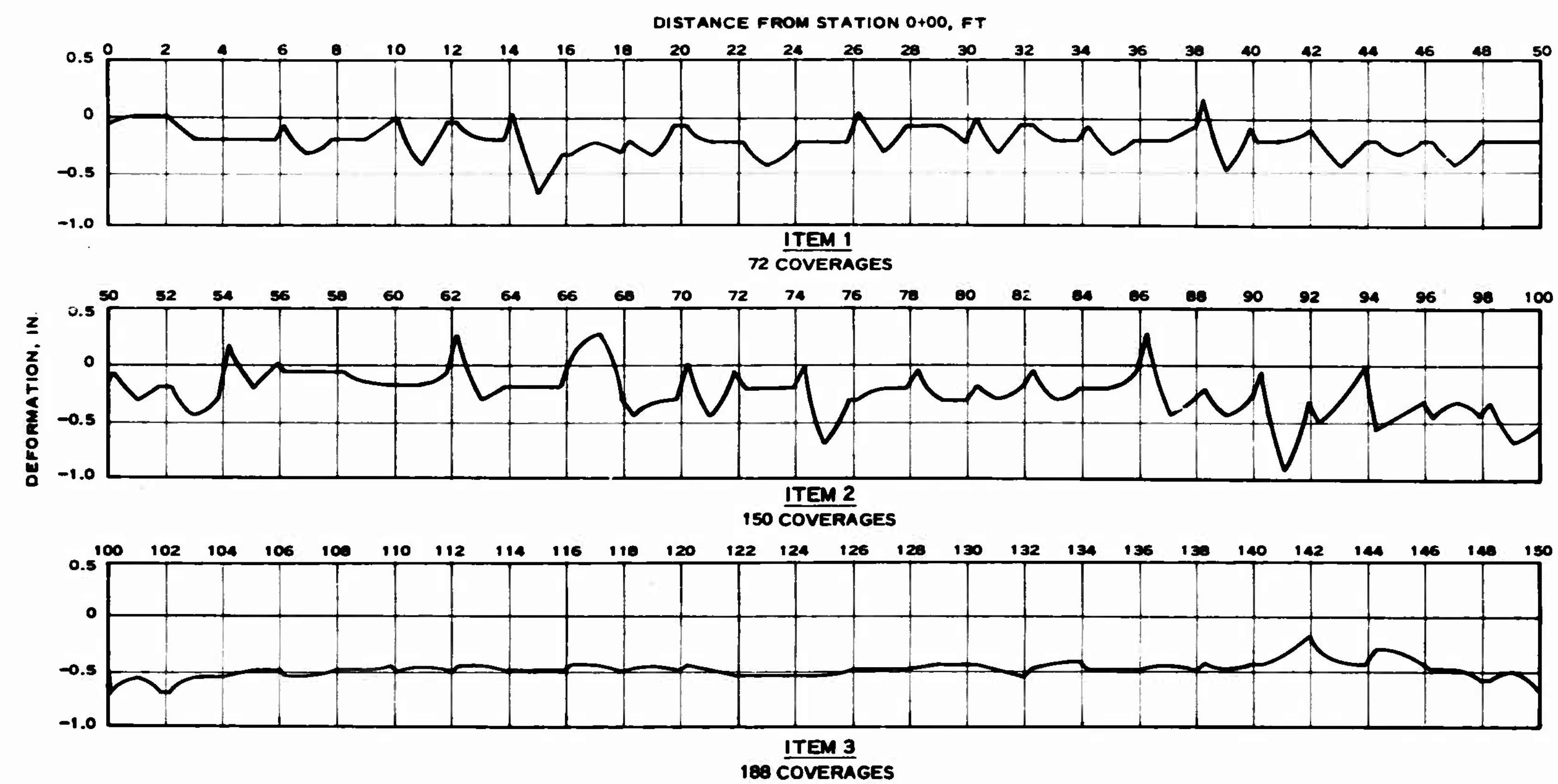


LEGEND

- JOINT AT CENTER LINE OF TRAFFIC LANE
- CENTER OF PLANK AT CENTER LINE OF TRAFFIC LANE

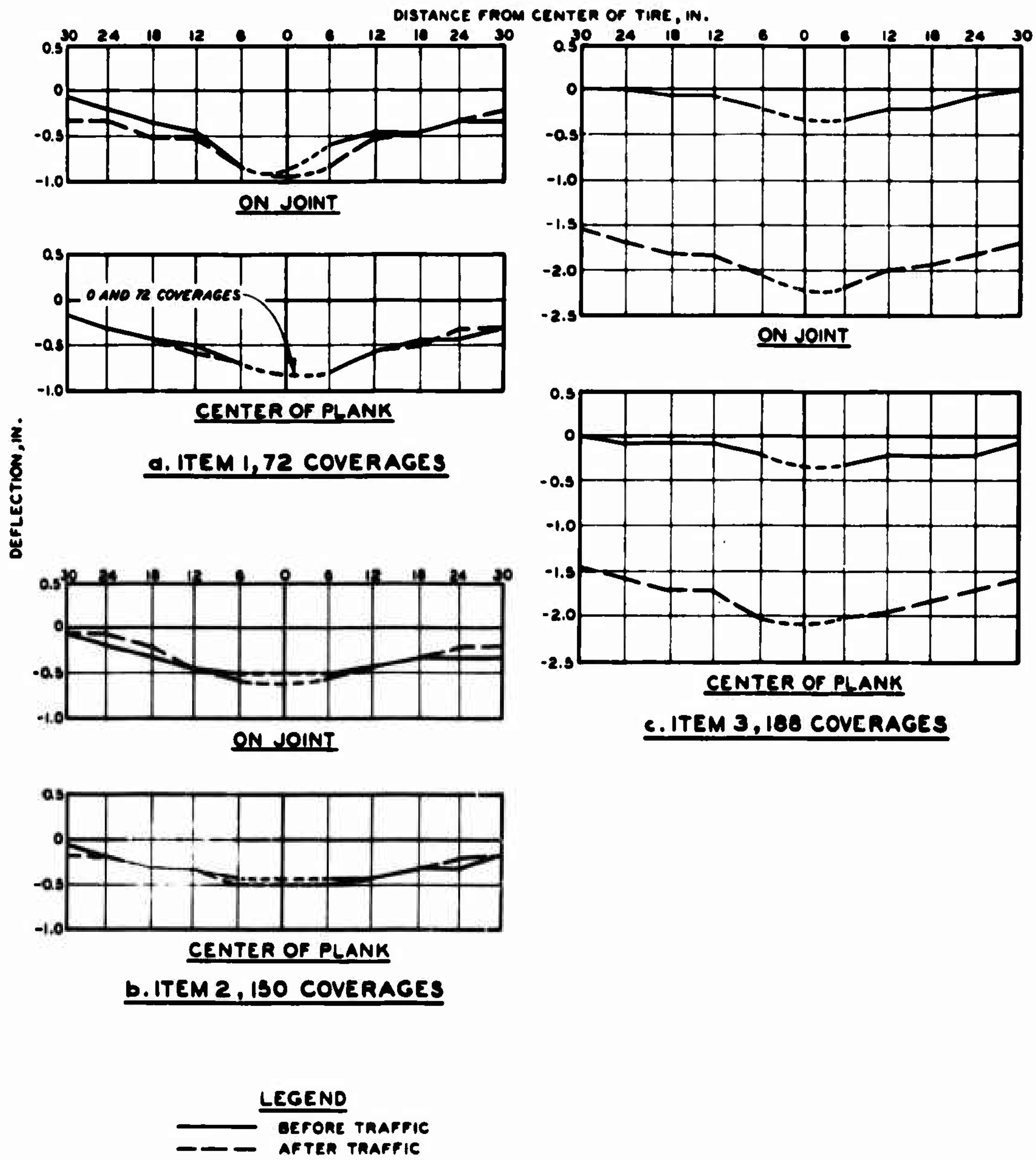
PERMANENT MAT DEFORMATION

27,000-LB SINGLE-WHEEL LOAD
UNIFORM-COVERAGE TRAFFIC



CENTER-LINE PROFILES
27,000-LB SINGLE-WHEEL LOAD
UNIFORM-COVERAGE TRAFFIC

PLATE 4



ELASTIC DEFLECTIONS OF MAT

27,000-LB, SINGLE-WHEEL LOAD

UNIFORM-COVERAGE TRAFFIC

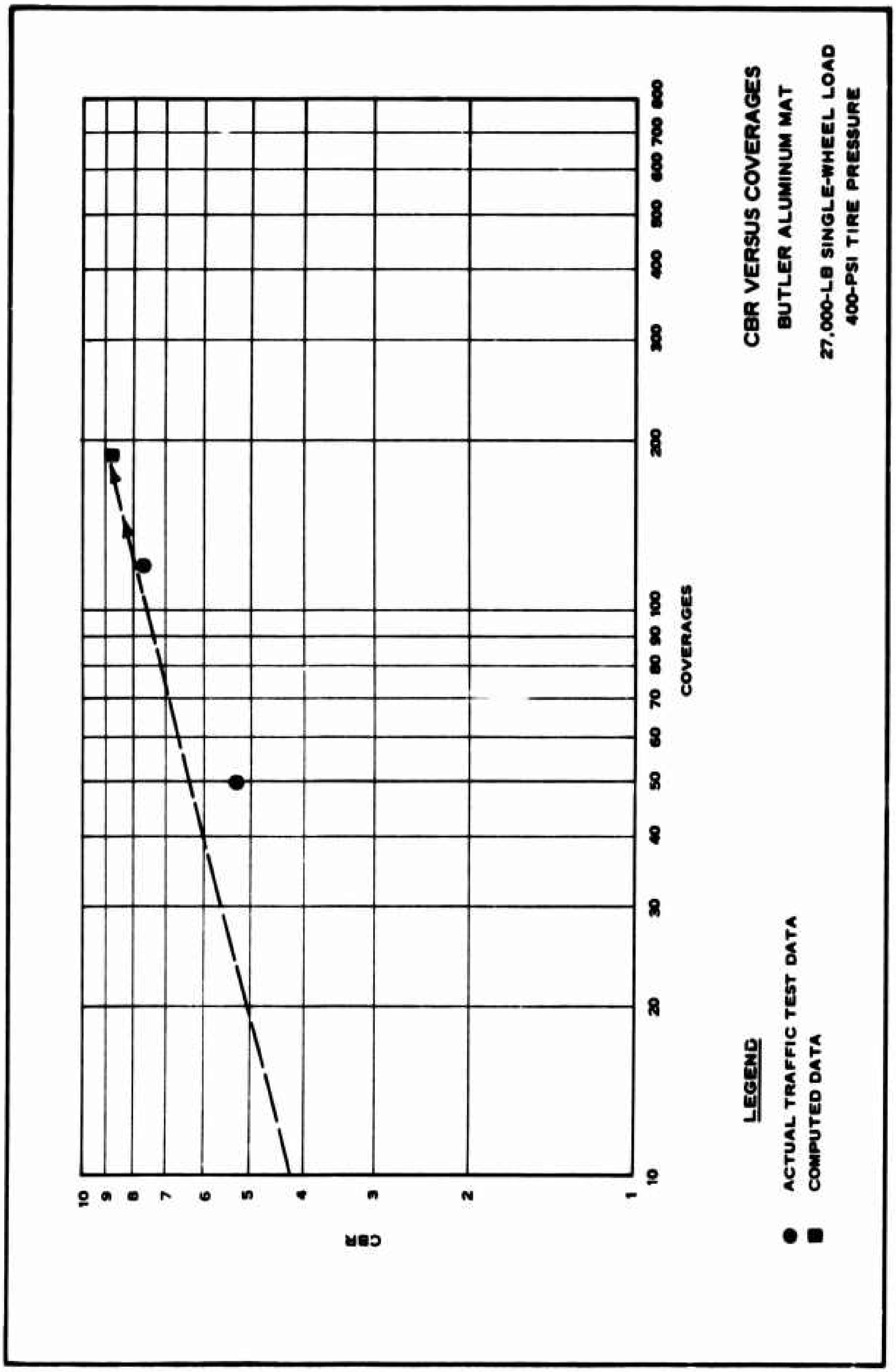
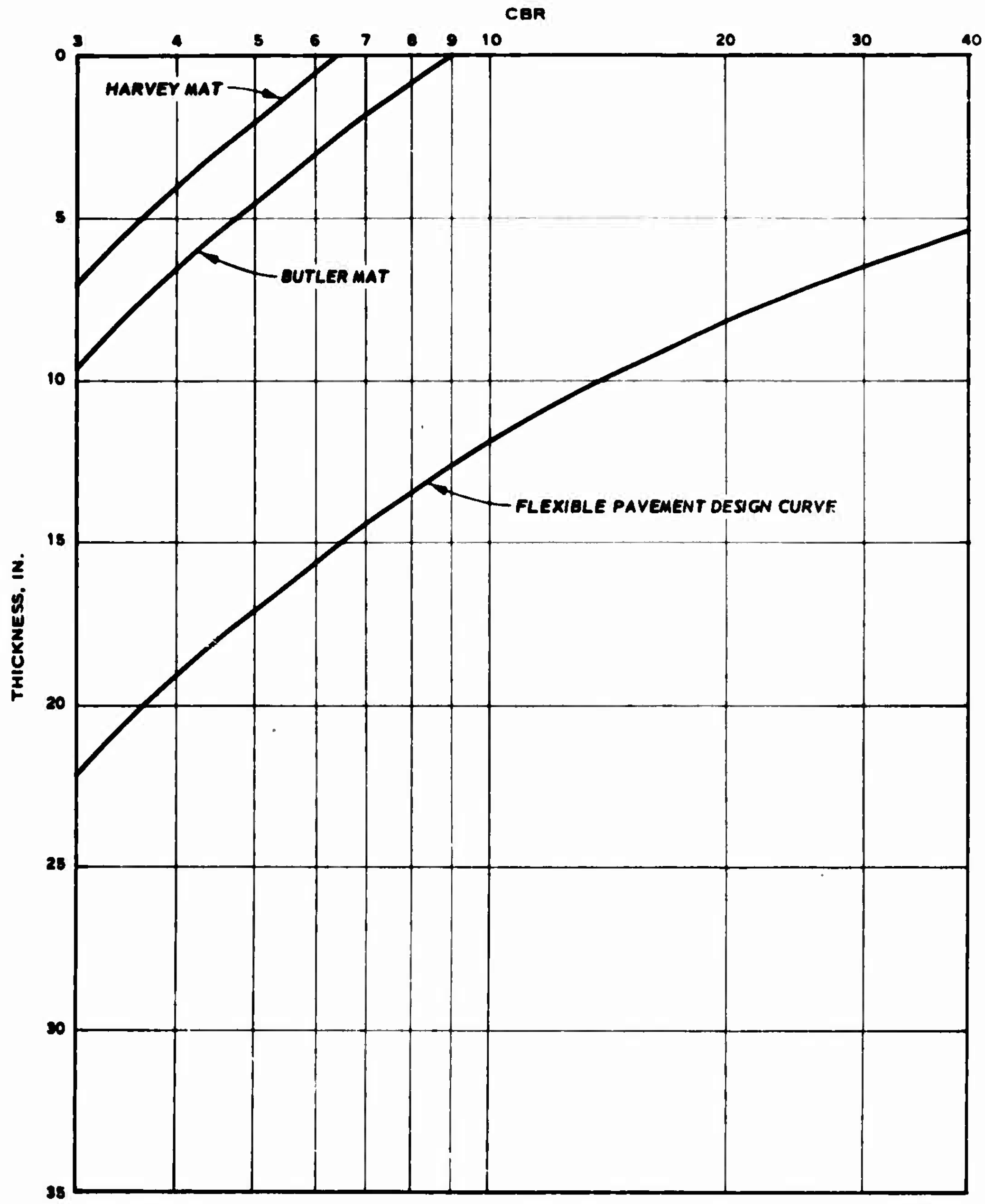
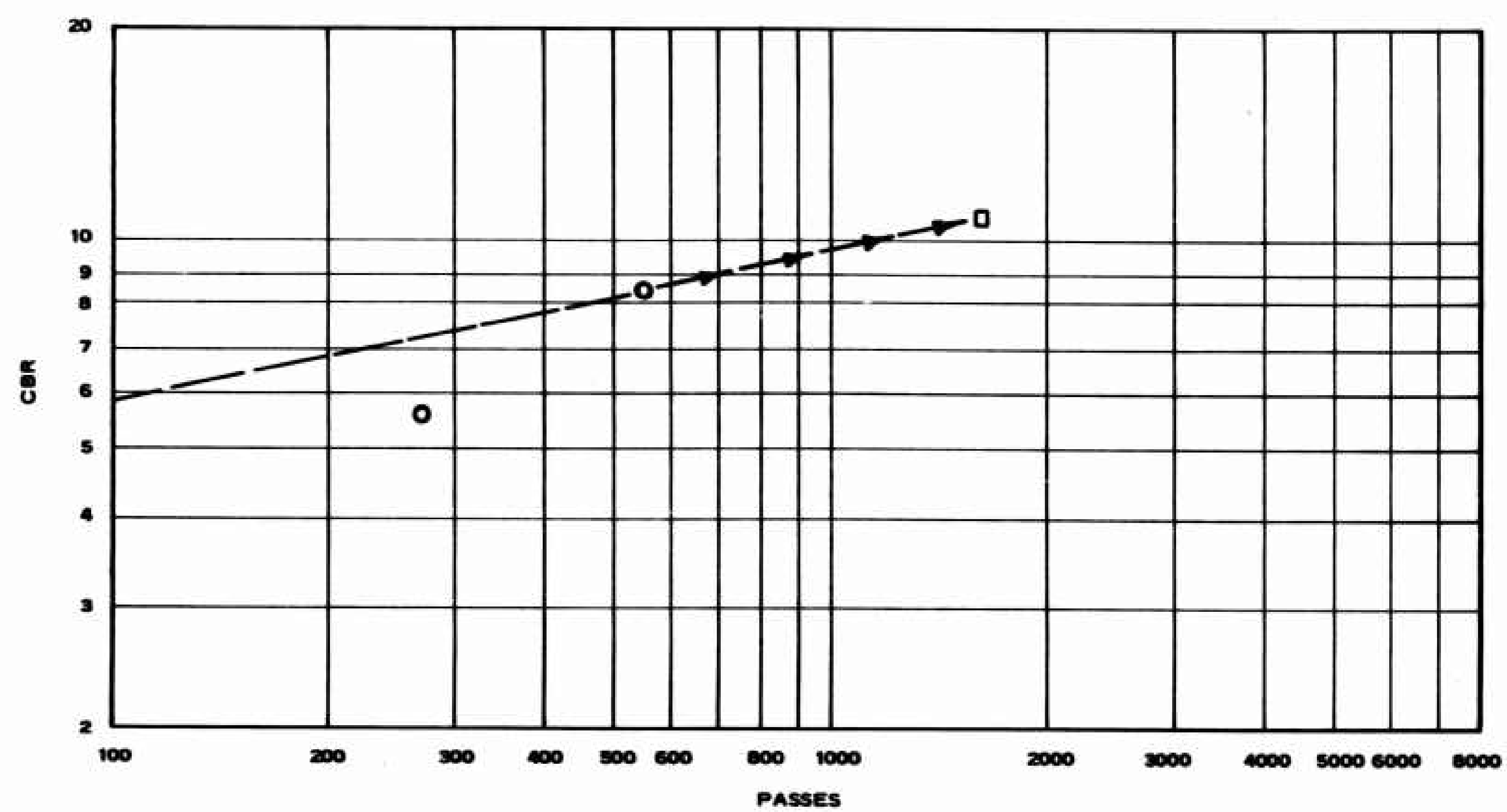

CBR VERSUS COVERAGES
BUTLER ALUMINUM MAT
27,000-LB SINGLE-WHEEL LOAD
400-PSI TIRE PRESSURE
LEGEND
ACTUAL TRAFFIC TEST DATA
COMPUTED DATA
COVERAGES
10 20 30 40 50 60 70 80 90 100 200 300 400 500 600 700 800
CBR
1 2 3 4 5 6 7 8 9 10

PLATE 6



CBR DESIGN CURVES
27,000-LB SINGLE-WHEEL LOAD
400-PSI TIRE PRESSURE
188 COVERAGES



LEGEND

O FAILURE POINTS FROM TRAFFIC TEST DATA

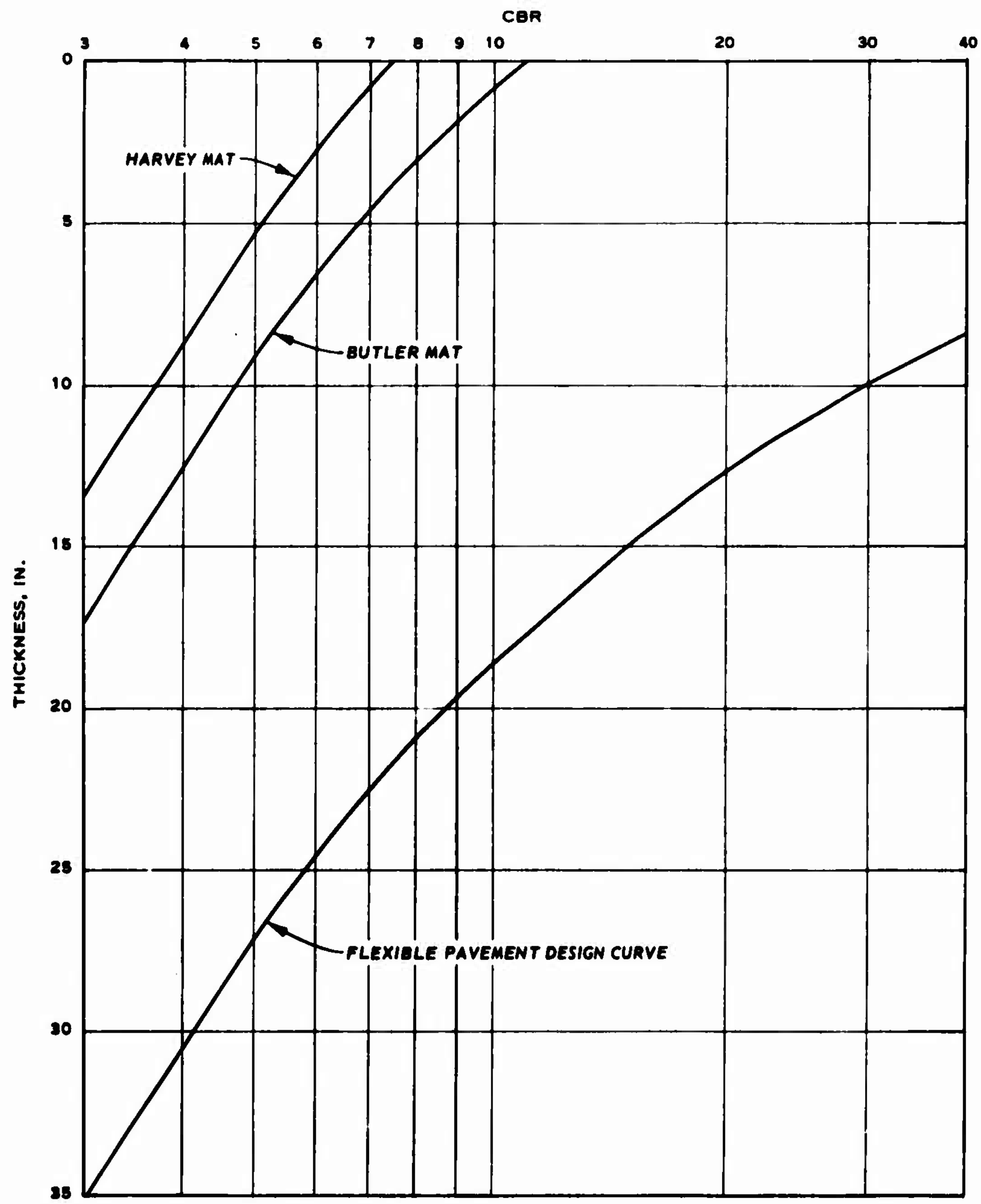
□ COMPUTED FAILURE POINT FOR 1600 PASSES

CBR VERSUS PASSES

BUTLER ALUMINUM MAT

39,000-LB SINGLE-WHEEL LOAD

400-PSI TIRE PRESSURE



CBR DESIGN CURVES

39,000-LB SINGLE-WHEEL LOAD

400-PSI TIRE PRESSURE

1600 PASSES